

Supplementary material

Early growing season immobilisation affects post-tillering wheat nitrogen uptake from crop stubble and ¹⁵N fertiliser in a sandy soil

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Table S1. Chemical characteristics of the soils* collected from 0-10cm depth in the field after a lupin or wheat crop and used for the top layer (0-10 cm) in the glasshouse experiment

EC, electrical conductivity; PBI, phosphorus buffering index; P, phosphorus; DTPA,

diethylenetriamine pentaacetic acid; DGT-P, diffusive gradient in thin-films-Phosphorus.

Soil history	After wheat	After lupin	Critical values**
pH 1:5 (H ₂ O)	7.1	7.0	
EC (dS m ⁻¹)	0.1	0.1	
PBI Index	8.0	12.0	<10
Colwell P (23.0	23.0	<15-45
Nitrate (mg kg ⁻¹)	3.6	5.6	10-50 desirable
Ammonium (mg kg ⁻¹)	1.5	2.3	5 desirable
DTPA Zn (mg kg ⁻¹)	1.8	1.3	<0.3-0.8
DTPA Cu (mg kg ⁻¹)	0.4	0.4	<0.2
DTPA Mn (mg kg ⁻¹)	1.8	1.8	<10
DTPA Fe (ug L ⁻¹)	17.0	18.0	<5
DGT-P	194	192	<20

*Bulked air-dried soil samples analysed by APAL on 20/9/17. ** According to APAL and

documented at: <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/08/trace-elements-copper-and-manganese-their-role-requirements-and-options>.

Table S2. Plant and soil analysis completed at each sampling time during the experiment.

Sampling date	22 September	9 October	19 October	30 October
Growth stage	Sowing	Tillering	First node	Booting
Days after sowing	0	18	28	39
<i>Plant analysis</i>				
Roots		Biomass, ¹⁵ N uptake	Biomass, ¹⁵ N uptake	Biomass, ¹⁵ N uptake
Shoots		Biomass, ¹⁵ N uptake	Biomass, ¹⁵ N uptake	Biomass, ¹⁵ N uptake
<i>Soil analysis</i>				
0-10 cm layer	Total N, Mineral N, gravimetric water, PMN, MBN, DON	Mineral N, gravimetric water, MBN	Mineral N, gravimetric water, MBN	Mineral N, gravimetric water, MBN
0-20 cm layer	Mineral N, gravimetric water	Mineral N, gravimetric water	Mineral N, gravimetric water	Mineral N, gravimetric water

Table S3. Soil nitrate N (NO₃⁻), and ammonium N (NH₄⁺, mg pot⁻¹) at 0-10 cm depth, and at 10-20 cm depth for all treatments at different wheat growth stages

Mean value of 4 replicates with standard deviation in parenthesis. Different letters indicate significant differences between ‘stubble treatment’ and ‘fertiliser N’ within each growth stage (DGC test, $p < 0.05$). NA, not available data. Values were highlighted in grey to improve visualisation of the significant differences among treatment means.

Treatment	Tillering		First node		Booting	
	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺
<i>Soil mineral N (mg pot⁻¹) at 0–10 cm depth</i>						
No stubble-N	2.8 (1.4) b	6.2 (2.4) a	5.2 (0.3) a	2.4 (0.3) a	4.5 (0.1) a	1.0 (0.1) a
No stubble+N	11.0 (4.0) a	2.9 (0.6) a	4.9 (0.2) a	2.0 (0.1) a	4.3 (0.1) a	0.9 (0.1) a
Wheat-N	4.8 (1.1) b	3.3 (1.1) a	4.9 (0.1) a	2.6 (0.2) a	4.5 (0.2) a	1.2 (0.2) a
Wheat+N	5.1 (1.5) b	3.5 (1.3) a	5.1 (0.1) a	2.3 (0.1) a	NA	NA
Lupin-N	3.5 (1.7) b	4.7 (0.9) a	5.0 (0.1) a	2.1 (0.2) a	4.5 (0.1) a	1.2 (0.2) a
Lupin+N	5.0 (1.5) b	3.6 (1.1) a	4.9 (0.2) a	2.2 (0.0) a	4.3 (0.1) a	1.1 (0.2) a
<i>Soil mineral N (mg pot⁻¹) at 10–20 cm depth</i>						
Treatment	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺
No stubble-N	1.8 (1.5) a	2.7 (0.9) a	4.4 (0.2) a	2.2 (0.2) a	4.4 (0.2) a	1.1 (0.3) a
No stubble+N	6.1 (3.2) a	6.1 (3.9) a	4.7 (0.1) a	1.5 (0.1) a	4.5 (0.1) a	1.2 (0.0) a
Wheat-N	0.3 (2.2) a	1.6 (1.5) a	4.5 (0.1) a	2.2 (0.1) a	4.3 (0.1) a	1.1 (0.1) a
Wheat+N	2.9 (1.2) a	4.4 (1.5) a	4.9 (0.2) a	2.1 (0.1) a	NA	NA
Lupin-N	1.8 (1.1) a	2.7 (0.4) a	4.3 (0.1) a	2.2 (0.1) a	4.4 (0.3) a	1.1 (0.1) a
Lupin+N	6.1 (1.2) a	6.1 (0.9) a	4.3 (0.1) a	1.5 (0.2) a	4.5 (0.1) a	1.2 (0.2) a
<i>Sum of soil mineral N (mg pot⁻¹) at 0–20 cm depth</i>						
Treatment	NO ₃ ⁻ +NH ₄ ⁺		NO ₃ ⁻ +NH ₄ ⁺		NO ₃ ⁻ +NH ₄ ⁺	
No stubble-N	13.4 (1.3) b		14.2 (0.2) a		11.0 (0.2) a	
No stubble+N	26.1 (1.4) a		13.1 (0.4) a		11.0 (0.1) a	
Wheat-N	12.2 (1.2) b		14.2 (0.3) a		11.1 (0.2) a	
Wheat+N	18.9 (1.2) b		14.0 (0.2) a		NA	
Lupin-N	10.1 (1.5) b		13.6 (0.2) a		11.1 (0.2) a	
Lupin+N	16.0 (2.1) b		13.6 (0.1) a		10.5 (0.1) a	

Table S4. Wheat plant root biomass (g) for the fertiliser N treatments at tillering and first node wheat growth stages. Mean values with standard error in brackets

+N, plus N with 40 kg N ha⁻¹ applied at wheat sowing time, -N, minus N, 0 kg N ha⁻¹ no fertiliser N added throughout the experiment. Mean value of 12 replicates with standard deviation in parenthesis. Different letters indicate significant differences between 'growth stage' and 'fertiliser N' (DGC test, $p < 0.05$). Values were highlighted in grey to improve visualisation of the significant differences among treatment means.

	Fertiliser N treatment	+N	-N
Wheat growth stages	Tillering	0.3 (0.0) c	0.3 (0.0) c
	First node	2.6 (0.2) a	1.8 (0.2) b

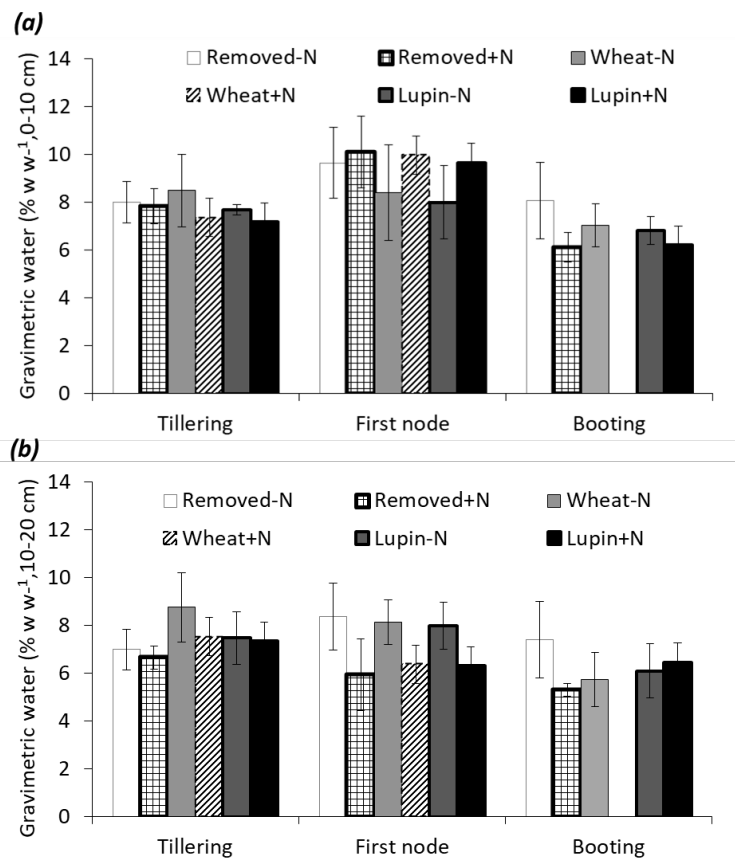


Figure S1. Soil gravimetric water (% w w⁻¹) for the stubble and N fertiliser treatments at different growth stages for the 0–10 cm soil depth (a), and for the 10–20 cm soil depth (b). Wheat stubble+N treatment data at booting not available (missing data). Between tillering and first node, differences between the interaction of ‘stubble treatment’, ‘fertiliser N’, ‘growth stage’ were not significant (ns, DGC test, p<0.05). At booting, differences between the interaction of ‘stubble treatment’, ‘fertiliser N’, ‘growth stage’ were not significant (DGC test, p<0.05).